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INTEGRATION OF SPT (N-VALUE), MACKINTOSH PROBE (M-VALUE) AND RESISTIVITY VALUES FOR SOFT SOIL ASSESSMENT

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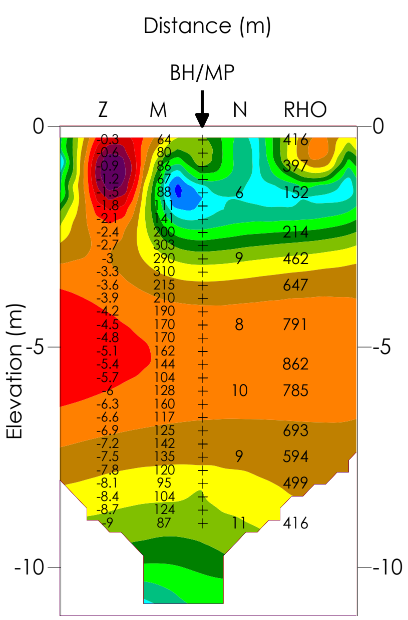
Graphical abstract



Abstract

2-D resistivity method has been used in association with Mackintosh probe and Standard Penetration Test (SPT) to investigate the ground properties at Universiti Sains Malaysia, Pulau Pinang. The purpose of this study was to determine the resistivity value of the subsurface material together with N-value and M-value of the particular location. The study also aimed to evaluate whether there is any correlation could be made by the parameters measured. Borehole record revealed that two types of soil exist up to 13 m; loose sand and stiff sandy silt. The loose sand recorded N-value of 8 and M-value of 170 having resistivity value of 790 Ohm.m. On the other hand, stiff sandy silt recorded N-value of 9-11, M-value of 135-170 and showing resistivity value of 415-785 Ohm.m. The results showed no clear relation between those geotechnical strength parameters with the resistivity imaging result. It is due to non-existence of distinctive differences in the electrical conductivity of the mentioned ground material when they are in the low strength bracket. However, the resistivity result suggested the presence of higher resistance material that is dry loose sand. The resistivity result was able to detect the water saturated zone near the ground surface, which showed low N-value and M-value.

Keywords: 2-D resistivity imaging; N-value; M-value

Abstrak

Kaedah pengimejan keberintangan 2-D digunakan bersama dengan maklumat lubang gerudi dan Mackintosh untuk mengkaji cirian tanah di Universiti Sains Malaysia, Pulau Pinang. Tujuan kajian ini dijalankan adalah untuk menyiasat nilai keberintangan bahan bawah permukaan bersama nilai N dan M. Kajian ini juga bertujuan untuk menilai samada terdapat kaitan yang boleh dibuat dengan parameter yang diuji. Rekod lubang bor mendapati bahawa dua jenis tanah hadir sehingga kedalaman 13 m iaitu tanah berpasir longgar dan kelodak berpasir. Tanah berpasir menunjukkan nilai N sebanyak 8 dan M sebanyak 170 serta nilai keberintangan 790 Ohm.m. Manakala kelodak berpasir pula merekodkan nilai N sebanyak 9-11 dan nilai M pula adalah 135-170, serta nilai keberintangan 415-785 Ohm.m. Keputusan kajian menunjukkan tiada perkaitan jelas dengan parameter kekuatan tanah dengan nilai keberintangan. Ini adalah kerana tiada perbezaan ketara bagi nilai kekuatan tanah yang boleh menyebabkan nilai keberintangan berubah. Kajian juga mendapati bahawa nilai keberintangan yang lebih tinggi dapat dikesan pada lapisan tanah kering berpasir longgar. Juga pada zon tepu yang mempunyai nilai N dan M yang rendah menunjukkan nilai keberintangan yang juga rendah.

Kata kunci: Pengimejan keberintangan 2-D; nilai N; nilai M

1.0 INTRODUCTION

Geophysical method has been used nearly 70 years, although predominantly in the exploration for natural resources [1]. 2-D resistivity is yet another powerful geophysical method, which uses an electrical current, that being sent through the subsurface by electrodes (C_1 and C_2) and measures potential difference (ΔV) between potential electrodes (P_1 and P_2), which is used to calculate apparent resistivity (ρ_a). This method is frequently used to evaluate aquifers, wells and plumes, environmental aspects of landfills, detection of voids and boulders, locating fracture zones or weak zones and determination of depth to bedrock [2].

A relationship between soil strength (N-value) and resistivity value might exist however resistivity is sensitive to fluid especially on salinity of saturating fluid whereas there is no connection with soil strength. Therefore, the relationship between resistivity and soil strength (N-value) is poor [4]. In geotechnical studies, resistance of soil to penetration is vital information, which can be used to evaluate the soil strength based on N-value from Standard Penetration Test (SPT). SPT is widely used as direct method to analyze the ground stiffness, but difficult to accurately identify the soil strength as the changes in N-value from different type of soil are minimal [5-6].

Geophysical methods have become crucial in foundation studies, since it could be used as an alternative method to provide subsurface information. Therefore, a subsurface exploration should embrace surface geological survey, geophysical investigation and in-situ engineering or laboratory tests [7]. The characterization of in-situ soils depends upon several factors, hence it is essential to scrutinize the behaviors through different approaches such as geology, geomorphology, climatology and other related factors [8]. This paper presents the correlation found between geophysical (ρ) and geotechnical values (N-value; M-value) for soft soil at Universiti Sains Malaysia, Pulau Pinang.

2.0 METHODOLOGY

The principle of 2D resistivity is measurement of material behavior to retard the flow of electrical current or resistance to movement of charge [9]. The resistivity measurements normally made by injecting current into the ground, and measures potential difference. Electrical resistivity surveys have been used for many decades in hydrogeological, mining, geotechnical investigations and environmental surveys [2].

The 2-D resistivity survey was carried out with a multi-electrode resistivity meter system (Figure 1). It usually uses 25 to 100 numbers of electrodes in a straight line with a constant spacing. A computer-controlled system will automatically select the active electrodes for each measurement [10].

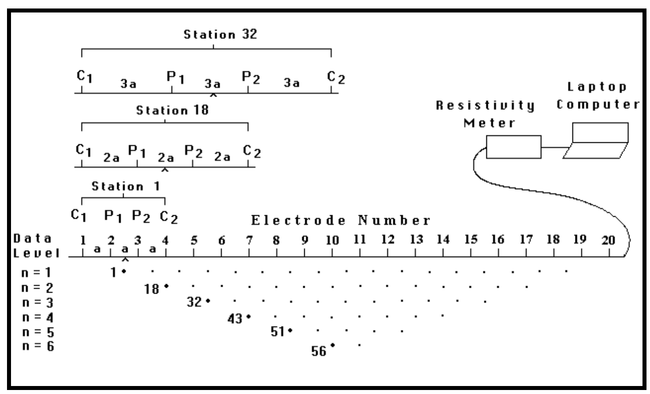


Figure 1 Typical arrangement for a 2-D resistivity survey used to build up a pseudosection (2)

Table 1 shows typical resistivity values of ground materials [11]. The resistivity values are mainly dependent on the ability to conduct electrical current and degree of fracturing. If water table is shallow, the fractures are normally filled with water and reduce the resistance [2].

Table 1 Resistivity of some common geological materials [11]

Rock Type	Resistivity (Ohm.m)
Granite	$3 \times 10^2 - 10^6$
Granite (weathered)	$3 \times 10 - 5 \times 10^2$
Schist (calcareous and mica)	$20 - 10^4$
Schist (graphite)	10×10^2
Clays	1×10^2
Alluvium and sand	$10 - 8 \times 10^2$
Consolidated shale	$20 - 2 \times 10^3$
Sand and gravel	30 – 225

Mackintosh probe test is widely used to assess soil bearing capacity mainly on soft ground (M-value). In this study, we used one set of 15 mm diameter series mackintosh probe with the length of 1.10 m each. A 25 mm diameter and 60 degree cone screwed onto the lower rod was driven into ground by a 4.5 kg hammer falling freely through a height of 30 mm onto an anvil. The number of blows require for every 300 mm penetration is recorded [3].

SPT is a dynamic, in situ penetration test used for gaining geotechnical engineering information of ground. The sample tube is driven into the ground using a 63.5 kg hammer, which is dropped freely at 760 mm height. The test results are deduced through the number of blows needed to penetrate 150 mm each up to 450 mm. Soil samples were collected for identification. Location of the borehole is located on the profile line at 14.35 m.

The 2-D resistivity survey was conducted using ABEM SAS4000 system with a total of 41 electrodes at 0.7 m constant spacing and Pole-dipole array. Borehole (BH) and mackintosh probe (MP) was conducted at 14.35 m on the 2-D resistivity line (Figure 2). Figure 3 shows the data acquisition and the 2-D resistivity data were processed using RES2Dinv and Surfer 8 software.

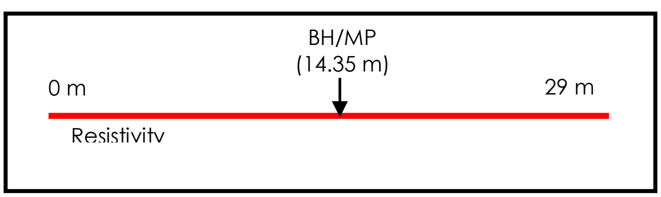


Figure 2 The position of BH and MP related to resistivity line

Figure 3 The resistivity and mackintosh probe data ecquisition

3.0 GENERAL GEOLOGY

Figure 4 shows the location of USM study area. Penang Island mainly landscaped by coastal plains, hill and mountains. Figure 5 shows the geological map of Penang, which indicates domination of granite in the island. Penang Island granites can be divided into North Penang and South Penang Pluton based on its mineralogy. The North Penang Pluton can be divided into Feringgi, Tanjung Bungah Granite while Mukah Head is microgranite. The South Penang Pluton is classified into Batu Maung and Sungai Ara Granite [12].

Figure 4 Location of study area

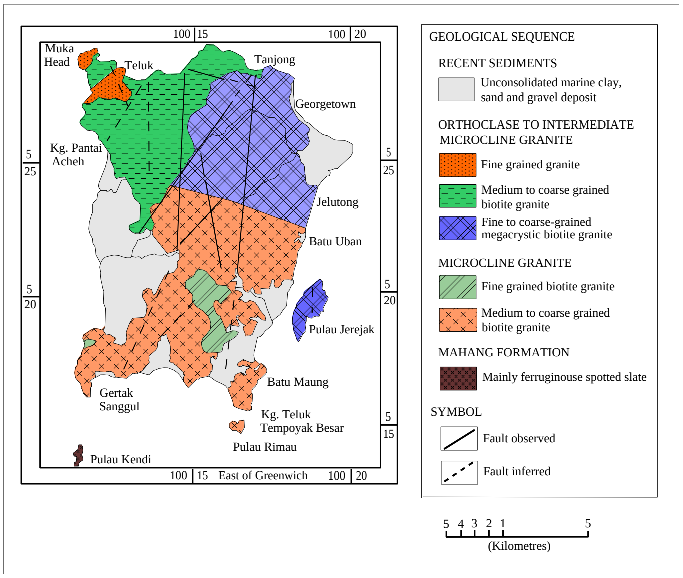


Figure 5 Geological map of Penang Island [11]

4.0 RESULTS AND DISCUSSION

The result of the 2-D resistivity, N-value and M-value are compared to gather a relationship that may exist. The 2-D inversion resistivity model shows this area was made up by resistivity zone of 56 -1160 Ohm.m with depth of 10 m (Figure 6). The resistivity image suggest below 3 m from the ground surface has low resistivity value of less than 200 Ohm.m except for the area at distance 12 m and 18 to 30 m which show resistivity of more than 800 Ohm.m. The blue coloured image above the harder ground could be trapped moist zone. Those higher resistivity value areas suggest harder ground or boulders could exist at this zone. Below 3 m depth, the resistivity image suggests stiffer or denser ground at distance 0 to 20 m with resistivity value of more than 500 Ohm.m. At ground distance of 20 to 30 m indicates softer material with value of less than 500 Ohm.m. The resistivity result shows significant variation of resistivity of subsurface at different depths along the profile line. This indicates wide variation in soil properties, type, strength and water saturation.

Table 2 and Table 3 show borehole and mackintosh probe test record respectively. The borehole test recorded stiff sandy silt with N-value of 9 at depth of 3 m. Below 3 m, loose sand and stiff to very stiff sandy silt are recorded with N-value of 8 to 17. Stiff to very stiff sandy silt could be regarded as residual soil of granite. Generally, the N-values increase with depth.

The mackintosh probe test showed increase in M-value of 64 to 303 with depth to 3 m. Below 3.6 m, the M-value decrease in its value to 117 at 6.9 m depth. From 7 to 10 m, the M-value recorded 87 to 171. Between the depths of 10 m to 13 m, M-value increased from 225 to 310.

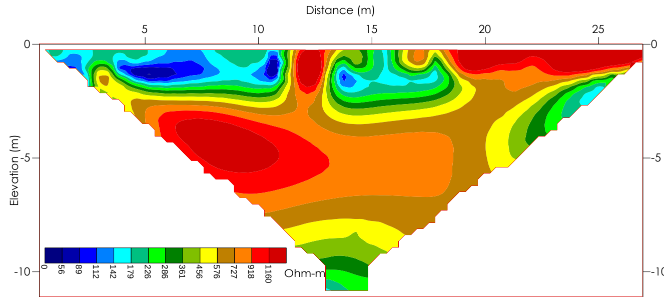


Figure 6 Inversion model of 2-D resistivity

Table 2 Borehole record

Depth (m)	Borehole data	
	N-value	Soil Description
1.5	6	No record
3.0	9	Stiff, sandy silt
4.5	8	Dry, Loose, sand
6.0	10	Stiff, sandy silt
7.5	9	Stiff, sandy silt
9.0	11	Stiff, sandy silt
10.5	14	Very stiff, sandy silt
12.0	16	Very stiff, sandy silt
13.5	17	Very stiff, sandy silt

Table 3 Mackintosh probe record

Depth (cm)	Number of blow (M-value)	Depth (cm)	Number of blow (M-value)
0 – 30	64	690 – 720	142
30 – 60	80	720 – 750	135
60 – 90	86	750 – 780	120
90 – 120	67	780 – 810	95
120 – 150	88	810 – 840	104
150 – 180	111	840 – 870	124
180 – 210	141	870 – 900	87
210 – 240	200	900 – 930	120
240 – 270	303	930 – 960	175
270 – 300	290	960 – 990	172
300 – 330	310	990 – 1020	171
330 – 360	215	1020 – 1050	225
360 – 390	210	1050 – 1080	210
390 – 420	190	1080 – 1110	211
450 – 480	170	1110 – 1140	17
480 – 510	170	1140 – 1170	250
510 – 540	162	1170 – 1200	197
540 – 570	144	1200 – 1230	223
570 – 600	104	1230 – 1260	225
600 – 630	128	1260 – 1290	243
630 – 660	160	1290 – 1320	310
660 – 690	117		

Figure 7 and Table 4 show comparison of resistivity, N-value and M-value at distance 14.35 m. The resistivity image of subsurface condition can be used as a tool for electrical characterization of ground material. By comparing the value with N and M-value, effort could be made to understand the relationship between electrical imaging with geotechnical parameter.

The borehole result revealed two types of soil; loose sand and stiff to very stiff sandy silt. The loose sand has N and M-value of 8 and 170 respectively. While the resistivity value is 790 Ohm.m. However, stiff sandy silt recorded N and M-value of 9-11 and 135-170, respectively. The resistivity value for this material ranges from 415-785 Ohm.m.

Saturated zone that being detected near the surface has low M-value and N-value. In saturated zone, electrical current flow through ions present. Sandy silt was detected at this part. Silty soil matrix has fine texture and the tendency for electrical current flow easily through the pore fluid, resulting lower resistance [13].

No specific relationships on strength parameter (M-value and N-value) are observed from the comparison with resistivity value. Similar result also been reported by Giao [4]. In soft soil consisting sand and sandy silt, the difference in its strength is low to capture the difference in the electrical conductivity of the material. However, higher resistivity value is recorded at 4.5 m depth where loose sand is detected. Dry loose sand could have higher resistance due to low electrical conductivity.

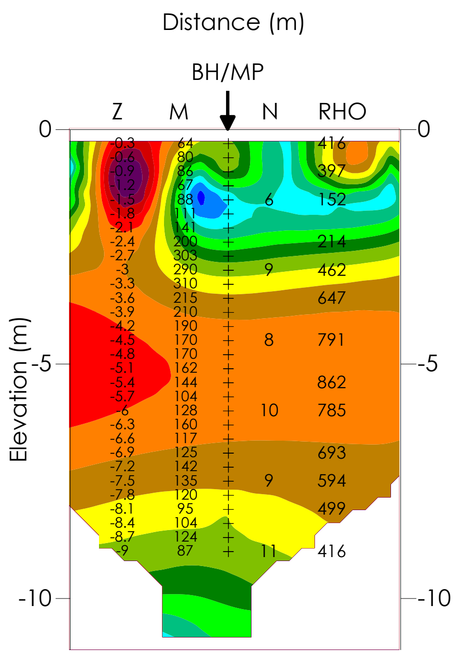


Figure 7 Comparison of resistivity, N-value and M-value

Table 4 Summary of result on resistivity, N-value and M-value

Depth (m)	Resistivity (Ohm.m)	Mackintosh (M-value)	Borehole data	
			N-value	Soil Description
1.5	151	111	6	No record
3.0	461	310	9	Stiff, Sandy silt
4.5	790	170	8	Dry, Loose sanc
6.0	785	128	10	Stiff, Sandy silt
7.5	593	120	9	Stiff, Sandy silt
9.0	415	120	11	Stiff, Sandy silt

The results of resistivity, M-value and N-value of the studied location are shown in Figure 8. Below 2 m from the ground surface show low value of the parameters measured. This is the saturated area as suggested by the resistivity image. However as deeper depth, no clear relation between resistivity and the geotechnical strength parameters can be observed. At the depth of 4 to 6 m, high resistivity value was observed due to higher electrical resistance of the ground. However, the strength parameter measured by M-value and N-value did not indicate stronger material as the value is 170 and 8 respectively (4.5 m).

At depth of 6 m, the M-value and N-value is 128 and 10 respectively. The high resistivity value could be from dry loose sand, which has more resistance in conducting the electrical current. The poor correlation between geotechnical (strength) and chargeability parameters also been reported by Braga *et al*. [14].

Other parameter such as distinctive difference of grain size, porosity and cementation of the soil will lead to contributing factors of the electrical conductivity. If higher amount of clay is present, the ions will facilitate the conductivity of current [13]. This can be seen the decreasing of resistivity value from depth 6 to 10 m where sandy silt is present. This result suggests that resistivity value could be used to predict different type of ground material especially when it has distinctive differences in the electrical conductivity.

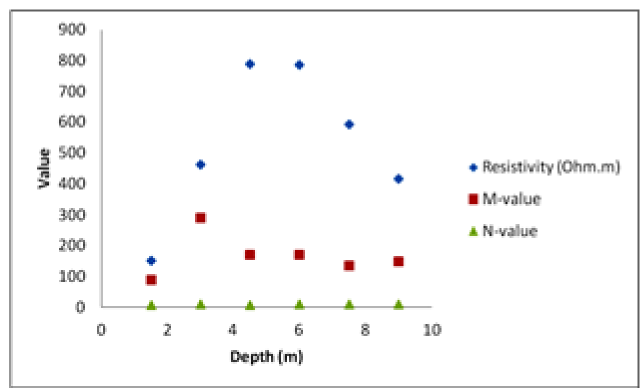


Figure 8 Relation of resistivity, N-value and M-value with depth

5.0 CONCLUSION

Geotechnical and geophysical investigation have been carried out on the same profile line in loose sand and stiff sandy silt in Penang. SPT value (N-value) and Mackintosh probe result (M-value) have been integrated with resistivity results. The result found no clear relation between those geotechnical strength parameters with the resistivity imaging result. It is due to non-existence of distinctive differences in the electrical conductivity of the mentioned ground material when they are within similar low strength bracket. However, the resistivity result suggested the presence of higher resistance material that is dry loose sand when compared to sandy silt. The water saturated area near the ground surface, which showed low N-value and M-value was detected to exhibit lower resistivity value. It is also worth to note that the relation is site specific and sensitive to lithology of the subsurface, which require extensive study to establish its validity and limitations.

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References

[1] Sirles, P.C. 2006. Use of Geophysics for Transportation Projects. *Transportation Research Board of the National Academies, Washington*. Nchrp Synthesis. 357.

[2] Loke, M. H. 1999. Electrical Imaging Surveys for Environmental and Engineering Studies. A Practical Guide to 2-D and 3-D Surveys: 1-10.

[3] Clayton, C.R.I., Simons, N.E., and Matthew, M.C. 1995. Site Investigation 2nd edn. *Blackwell Science, Oxford*.

[4] Giao, P.H. 2002. Electric Imaging and Laboratory Resistivity Testing For Geotechnical Investigation of Pusan Clay Deposits. 2003. *Journal Of Applied Geophysics.* 52: 157–175.

[5] Seokhoon, O. 2007. Combined Analysis of Electrical Resistivity And Geotechnical SPT Blow Counts For The Safety Assessment Of Fill Dam. *Environmental Geology*. 54: 31-42.

[6] Jung, H.S., Cho, C.G., and Chun, B. S. 2010. The Engineering Properties of Surface Layer on Very Soft Clay of the South Coast in Korea. *2nd International Symposium on Cone Penetration Testing.* Huntington Beach, Carlifornia.

[7] Ako, B.D. 1996. An Integration of Geophysical and Geological Data in Dumpsite Investigation - The Case of Dam. *Journal of Mineral and Geology.* 13(1): 1-6.

[8] Bery A. A. and Saad R. 2012. Clayey Sand Soil's Behaviour Analysis and Imaging Subsurface Structure via Engineering Characterizations and Integrated Geophysicals Tomography Modeling Methods. *International Journal of Geosciences.* 3(1): 93-104.

[9] Awang, H., Nawawi, M.N.M. and Mohamed, Z. 2009. Enhancing Geotechnical Investigation by Geoelictrical Method-Case Study. *Journal of the Southeast Asian Geotechnical Society*. 40(3): 158-192.

[10] Griffith, D.H. and Barker, R.D. 1993. Two Dimensional Resistivity Imaging and Modeling.

[11] Keller, G.V. and Frischknecht, F.C. 1996. Electrical Methods in Geophysical Prospecting. *Pergamon Press Inc., Oxford.*

[12] Ong, W.S. 1993. The Geology and Engineering Geology of Penang Island. *Geological Survey of Malaysia*.

[13] Zhdanov, M. S., Keller, G. V. 1994. *The Geoelectrical Methods In Geophysical Exploration.* Elsevier, Amsterdam.

[14] Braga, A., Malagutti, W., Dourado, J., Chang, H. 1999. Correlation of Electrical Resistivity and Induced Polarization Data with Geotechnical Survey Standard Penetration Test Measurements. *Journal of Environmental and Engineering Geophysics.* 4: 123–130.